A Dual-Cell-Gap Transflective Liquid Crystal Display with Identical Response Time in Transmissive and Reflective Regions

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Abstract

A dual-cell-gap transflective liquid crystal display (TR-LCD) with identical response time in the transmissive and reflective regions is demonstrated. In the transmissive region, strong anchoring energy condition is used to decrease the response time, while in the reflective region weak anchoring energy condition is used to increase the response time. The simulated dual-cell-gap TR-LCD has good performances.

1. Introduction

Combining both advantages of transmissive liquid crystal display (LCD)'s high contrast ratio and good color saturation and the reflective LCD's low power consumption, transflective liquid crystal display (TR-LCD) [1-6] can be used under any environment light conditions. In recent years, TR-LCD is emerging in mobile displays, such as mobile phones, e-books, and personal digital assistants, etc. The pixels in a TR-LCD are normally divided into transmissive and reflective regions so that the TR-LCD can work in transmissive or reflective mode, depending on the ambient light intensity. When the ambient light is bright, we can turn off the backlight and the TR-LCD works in reflective mode. On the other hand, when the ambient light is dark we can turn on the backlight and the TR-LCD works in the transmissive mode.

Two types of TR-LCDs have been developed: single-cell-gap and dual-cell-gap. A single-cell-gap TR-LCD has advantages in simple fabrication process and identical response time in the transmissive and reflective regions, however, its transmissive and reflective regions exhibit an optical path-length disparity because the backlight traverses the LC layer only once but the ambient light twice. As a result, it generally experiences difficulty in obtaining high transmissive and reflective optical efficiency simultaneously. On the contrary, a dual-cell-gap TR-LCD is designed to have high transmittance and reflectance and single gamma curve. However, its shortcomings are e.g., the reflective region has faster response time than the transmissive region and cell gap uniformity is difficult to control.

In this paper, we propose a dual-cell-gap TR-LCD with identical response time in the transmissive and reflective regions. By tuning the anchoring energy in the transmissive and reflective regions, the TR-LCD can obtain good electro-optic characteristics and identical response time in the transmissive and reflective regions.

2. Device structure and working principle

Figure 1 shows the schematic device structure and ope rating principle of the dual-cell-gap TR-LCD. On the top and bottom sides of the LC panel, a half-wave film and a quarter-wave film are laminated to the inner side of the polari zer to form a broadband circular polarizer. The two po larizers are crossed. Within each pixel, the LC cell is d ivided into transmissive and reflective regions. In the t ransmissive region, the LC layer is sandwiched betwe en the top transparent ITO electrode and the bottom I TO electrode. In the reflective region, the LC layer is sandwiched between the top transparent ITO electrode and the reflector. The cell gap of transmissive and ref lective regions is d_1 and d_2, respectively. When no voltage is applied, all the LC directors are vertically aligned. Therefore, the light passing through the LC la yer experiences no phase retardation and keeps its orig inal polarization state, resulting in a dark state for both transmissive and reflective regions. As the voltage ex ceeds a threshold, the LC directors are tilted and the p hase retardation effect takes place, resulting in a brigh t state for both transmissive and reflective regions. Ide ally, the required phase retardation is λ/2 for the trans missive region and λ/4 for the reflective region in orde r to achieve maximum transmittance and reflectance.

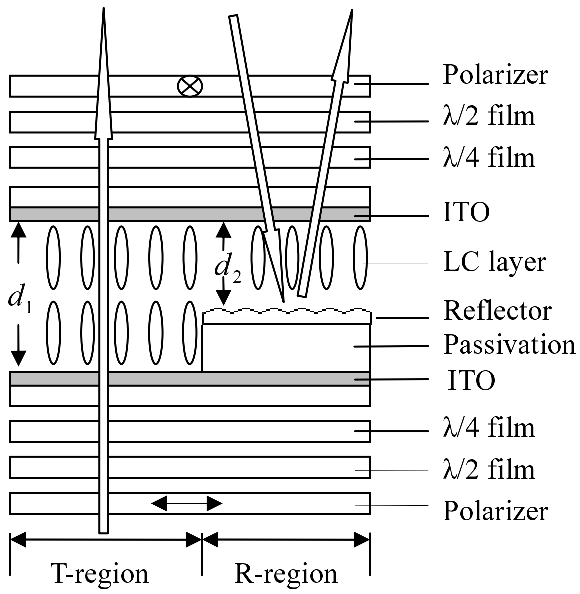

Figure 1 Schematic device structure and operating principle of a dual-cell-gap TR-LCD

In the transmissive region, strong anchoring energy condition on the top and bottom boundaries of LC cell is utilized to decrease the response time. In the reflective region, strong anchoring energy condition on the top boundary of LC cell and weak anchoring energy condition on the bottom boundary of LC cell are utilized to increase the response time. And overdrive voltage technique [7, 8] is applied to make the response time identical in the transmissive and reflective regions.

In order to calculate the LC response time, the weak anchoring cell of gap d_2 can be regarded as the strong anchoring cell of gap $d_2^{'}$ [9], so

$$d_2^{'} = d_2 + \frac{k_{33}}{C} \tag{1}$$

where k_{33} and C represent the bend elastic constant and anchoring energy, respectively.

On the strong anchoring energy condition, the threshold voltage V_{th} of the LC cell in the transmissive region is

$$V_{th} = \pi\sqrt{\frac{k_{33}}{\varepsilon_0\,|\Delta\varepsilon|}} \tag{2}$$

where k_{33} is the bend elastic constant, $\Delta\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp}$ is the dielectric anisotropy, $\varepsilon_{\|}$ and $\varepsilon_{\perp}$ is parallel and perpendicular dielectric permittivity, and ε_0 is the permittivity of vacuum, respectively.

The threshold voltage V_C [10] of the LC cell in the reflective region is

$$\sin(\pi\frac{V_C}{V_{th}}) = \frac{\pi k_{33}V_C}{Cd_2\sqrt{V_{th}^2 + (\frac{\pi k_{33}V_C}{Cd_2})^2}}. \tag{3}$$

The decay time t_d, rise time t_r, and response time t of LC cell are

$$t_d = \frac{\gamma d_1^{\,2}}{k_{33}\pi^2} \tag{4}$$

$$t_r = \frac{t_d}{|(\frac{V}{V_{th}})^2 - 1|} \tag{5}$$

$$t = t_d + t_r \tag{6}$$

In Eq. (4) and Eq. (5), γ is the rotational viscosity and V is the applied voltage. Under strong anchoring energy condition, we can obtain response time t_T in the transmissive region through Eqs. (4), (5) and (6). For the weak anchoring energy condition, d_1 and V_{th} are replaced by $d_2^{'}$ and V_C in Eqs. (4), (5) and (6), respectively, we can obtain response time t_R in the reflective region similarly.

3. Simulation results

To prove the concept, the difference iterative and extended Jones matrix methods were used to calculate the response time and electro-optic characteristics of the TR-LCD. For the VA cell, we applied a negative Δε Merck LC mixture MLC-6608 in simulation. Its parameters are: $n_e=1.5578$, $n_o=1.4748$ *(at $\lambda=589nm$)*, $\varepsilon_{\parallel}=3.6$, $\varepsilon_{\perp}=7.8$, $k_{11}=16.7pN$, $k_{22}=7.0pN$, $k_{33}=18.1pN$, $\gamma=0.186Pa\cdot s$. The other presumed parameters are listed as follows: $d_1=5\mu m$, $d_2=4.25\mu m$, $C=2.24\times10^{-5}J/m^2$, and the pre-tilt angle of LC is 88°. We define the polarization axis of the bottom polarizer is at an angle 0°. The polarization axis of the top polarizer is at an angle 90°. The optical axes of the half-wave film and quarter-wave film on the bottom side of the LC panel are oriented at angles 15° and 75°, respectively. And the optical axes of the half-wave film and quarter-wave film on the top side of the LC panel are oriented at angles -75° and -15°, respectively.

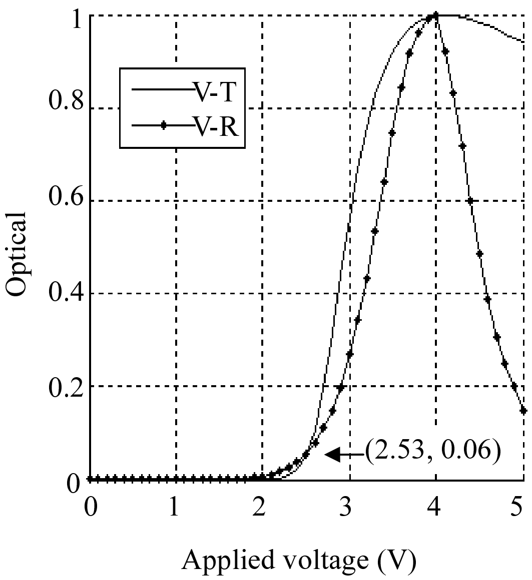

Figure 2 Simulated VT and VR curves of the dual-cell-gap TR-LCD

Through calculations, we find the effective cell gap for the reflective region $d'_2=5\mu m$ and threshold voltage $V_C=1.81V_{rms}$, and the threshold voltage of transmissive region $V_{th}=2.11V_{rms}$. Figure 2 shows the simulated voltage-dependent transmittance (VT) and reflectance (VR) curves for the TR-LCD. As shown in Figure 2, point (2.53, 0.06) is the intersection of VT and VR curves. When the voltage is less than 2.53V, the VR curve rises faster than the VT curve, because reflective region has a lower threshold voltage than transmissive region. When the voltage is between 2.53 V and 4 V, the VR curve rises more slowly than the VT curve. Because at lower voltages, the LC directors are more influenced by weak anchoring energy on the bottom boundary of the LC cell, and the phase retardation of reflective region is less than one-half of the transmissive region. When the voltage is 4V, the VR and VT curves reach the maximum value 1, that is, the optical efficiency in both transmissive and reflective regions reach 100%. So when the voltage is between 0V and 4V, the TR-LCD shows good electro-optic characteristics.

Figure 3 shows the voltage-dependent response time V-t_T and V-t_R curves in the transmissive and reflective regions. Due to the difference of threshold voltage and cell gap between the transmissive and reflective regions, when the voltage is between 2V and 5V, there is a greater difference between V-t_T and V-t_R curves. But when the voltage is between 5V and 6V, the V-t_T and V-t_R curves are almost superposed. So overdrive technology may be applied to make the response time identical in the transmissive and reflective regions in the premise of good electro-optic characteristics.

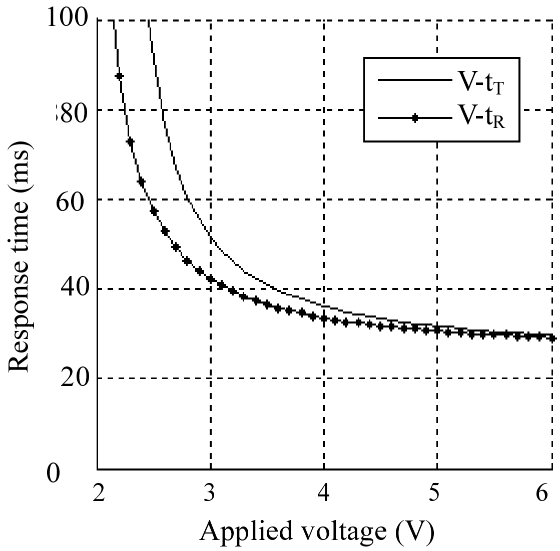

Figure 3 Simulated V-tT and V-tR curves of the dual-cell-gap TR-LCD

4. Conclusion

A dual-cell-gap TR-LCD with identical response time in the transmissive and reflective regions is demonstrated and simulated. In the transmissive region, strong anchoring energy condition is used to reduce the response time. In the reflective region, weak anchoring energy condition is used to increase the response time. And overdrive voltage method is adopted to make the response time identical in the transmissive and reflective regions. The dual-cell-gap TR-LCD has good performances.

5. References

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